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predictable, either. Adding small amounts of wind power (perhaps up to 10%) to a larger system adds little to the system's overall unpredictability and, as a practical matter, may hardly be noticed by operators.

Some strong preliminary evidence indicates that a customized mesoscale weather model does a good job of predicting the output of the wind farm on relevant time scales. On the whole, the future for wind power appears very bright.

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The articles in the April 2002 special Energy Challenge issue of PHYSICS TODAY seemed generally thoughtful and well-written. However, I was puzzled that nowhere in that issue, not even in Samuel Baldwin's renewable energy article (page 62) covering solar power, was there a mention of solar power satellites, lunar solar power, or the other space-based alternatives that, in the long run, can provide us with an astronomically large, completely renewable energy resource—for example tens of terawatts from (admittedly large) satellites in geosynchronous orbit. Considering that these options have, in the past, been advocated primarily by physicists, including Gerard O'Neill, Freeman Dyson, and others associated with the Space Studies Institute,[1] it seems derelict of PHYSICS TODAY to ignore the current status and future prospects of this energy option.

Fortunately, David Criswell provides an introduction to the lunar solar power option in a recent issue of *The Industrial Physicist*.[2] Space-based power has apparently suffered from NASA neglect at least since the 1970s, although an installed base of at least several hundred kilowatts is already in operation, powering satellites and the space station. Of course, there is always a battle for research funding, but the long-term potential usefulness of space-based solar power seems so immense that a more focused effort to develop this technology is long overdue.

References

1. For more information on the Space Studies Institute, see http://www.ssi.org.
2. D. Criswell, *The Industrial Physicist* **8**(2), 12 (2002).

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NSF Graduate Research Fellowships: A Missed Opportunity

Each year, the National Science Foundation awards its Graduate Research Fellowships (GRFs) to the nation's "best and brightest" students in mathematics, science, and engineering, to help support the early stages of their graduate study. As the chair (Boye) and members of the panel judging recent physics and astronomy (P/A) applications, we are concerned that the current selection criteria are not well understood. Some excellent candidates may not apply, thinking that grades and Graduate Record Examination (GRE) scores are of overriding importance. These students miss a career-defining opportunity. Fewer qualified P/A applicants also means that the proportion of awards in our field declines. Between 1996 and 2002, as the number of program awards rose from 765 to 900, the number in P/A actually fell—from 53 to 46.

The GRF provides three years of financial support to be used within a five-year period. The current stipend is $21 500. US citizens, US nationals, and permanent resident aliens who have completed no more than one year of graduate study are eligible to apply. For the 2002 competition, there were more than 6600 applicants overall, but just 376 of these were in P/A. We estimate that in P/A, only about 15% of those entering graduate school who meet the eligibility requirements actually apply, while the numbers of applications in other fields have grown tremendously due to proactive strategies that encourage qualified students.

We are also concerned by the underrepresentation of women and minorities among P/A applicants. The proportion of women in physics still decreases with each step up the academic ladder. Just 22% of P/A applicants in 2001–02 were women, and only 1% of P/A applicants came from historically black colleges and universities or institutions primarily serving Hispanic students.

We feel that faculty in P/A should seek out, encourage, and mentor strong candidates. The application

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process itself can be an important educational component, and mentors can discuss students' ideas with them and provide helpful guidance. Ultimately, of course, each application must represent the student's own best efforts. We offer some clarifications that may help students in P/A and their mentors.

NSF has two main selection criteria. The first criterion, "intellectual merit," includes the applicant's proposed plan of research, previous research experience, academic record, reference reports, and GRE test scores. The second criterion, "broader impact," includes three components: integration of research and education, potential contributions to diversity, and contributions to community. Although the most easily quantified measures such as grades and GRE scores remain important, these are clearly not the sole or determining factors. Panelists look for evidence of original thought, creativity, and depth of commitment to advancing science through research. A student with modest GRE scores who is highly distinguished in other ways has an excellent chance for a fellowship.

In describing proposed plans of research, the applicants' formulations of research questions and detailed descriptions of how they would address their questions reveal a lot about their thought processes. Candidates should focus on one or, at most, two research questions. A good plan includes background research to learn what projects are being pursued at the applicant's intended graduate institution. In describing their previous research experiences, applicants should state both what was accomplished and—perhaps more important—what they learned personally. Research experiences that extend beyond the applicant's own campus can indicate breadth of interest and motivation. It is of great importance that the applicant's writing be clear, concise, and free of grammatical and typographical errors.

The reference reports, both the letters and the rating sheet, are crucial. Panelists need specific information that gives a personal sense of each applicant. The most helpful reference letters provide insight into what makes the student exceptional, what the student has accomplished as a researcher, and how he or she thinks about physics. We urge faculty members to be specific, and to be consistent in the rating and the narration.

The "broader impact" criterion was the decisive factor for many applicants. But the questions related to that criterion were the most misunderstood. Panel members look for original, self-motivated contributions to the integration of research and education, such as the development of innovative teaching materials, significant volunteer work with science in local schools, or exceptional departmental service. "Potential contributions to diversity" refers to activities such as science advocacy that may help to increase the diversity of the US population that is entering science or is knowledgeable about it—for example, taking science to underrepresented population groups through work with schools or clubs. "Contributions to community" may include organizing or working with department-based initiatives, with science museums, or with students. Applicants and their mentors should address this point at the level of making a real difference in the lives of others.

The P/A panel and NSF value and encourage applicants who want to pursue a doctoral specialty in physics education research. From applicants in this field, we would expect great strength on the broader impact criterion as well as demonstrated intellectual excellence and an exceptional, carefully developed research plan.

In short, more physics and astronomy students with more diverse strengths should be encouraged to apply for these fellowships. There is no fixed recipe, no particular combination of ingredients that ensures success. Identifying and encouraging promising students and helping them present themselves effectively benefits both the students and the wider P/A community.

The application deadline for the 2003–04 fellowships is 7 November 2002. Application material is available online at http:www.ehr.nsf.gov/dge/programs/grf/. Our more detailed observations, supporting data, and suggestions are available at http://www.phy.davidson.edu/NSFRF.htm.

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Looking at Both Sides of Einstein's Gravitational Field Equation

The letter by Alex Harvey (Physics Today, February 2002, page 73) claims that the term $\Lambda g_{\mu\nu}$ is necessarily an ingredient of the geometrical, or left-hand, side of Einstein's gravitational field equation. The corresponding matter-free ($T_{\mu\nu}$ = 0) solution for $\Lambda > 0$ is the de Sitter space, which contains an embedded repulsive force driving particles apart. Accelerated cosmic expansion therefore appears as a natural consequence of the geometry of space-time. This view conflicts with the "majority opinion" by which the Λ term is identified with some kind of "dark energy."

Whichever side of Einstein's equation has Λ, the equations are still solved by the same curved de Sitter space-time, which contrasts with the flat Minkowski space-time obtained when Λ vanishes.

People nevertheless tend to distinguish the two cases because, on the right-hand side, the Λ term is another source of gravity, expressed by a constant times the stress-energy tensor ($\kappa T_{\mu\nu}$). Adopting $T_{\mu\nu} = (p + \rho)u_\mu u_\nu + pg_{\mu\nu}$, the form valid for a perfect fluid with energy density ρ and pressure p, one can define a Λ fluid by setting $\Lambda = \kappa\rho$. Then the two formulations agree for an equation of state $p = -\rho$.

Because Λ is a constant, ρ is constant as well, and such a fluid has negative pressure for positive ρ. The relabeling does not change the physics fixed by general relativity: The reformulated cases are equivalent. One should nevertheless be on the alert if ρ is not constant—even a slowly fluctuating field differs from the Λ case.

However, as long as ρ is constant, the difference between the two formulations lies only in the language used to describe physically identical situations. General relativists are well acquainted with similar apparent interpretational ambiguities when different coordinate systems are used to describe the same space-time geometry.

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